INTRODUCTION: ~1500 words (currently 1607 words)

Editorial Overview: Neuroscience of Education - by Dénes Szűcs, Fumiko Hoeft and John Gabrieli.

Research in the field of 'neuroscience and education' aims to provide educationally-relevant, and empirical evidence using the increasingly more integrated methods of neuroscience, psychology and education. It is important that studies in the field consider the needs of all disciplines and are open to cross-disciplinary communication. All three disciplines can inform each other in introducing methods, integrating potentially diverse research results and theoretical views, and setting research agendas. The diversity of the field in ideas, approaches, methods and theoretical views is key. Debate-free, uniform opinion rarely leads to scientific progress. The current special issue addresses current advances in some of the major topics in the field of educational neuroscience, i.e., the neuroscience of educationally relevant processes, from science, technology, education and mathematics (STEM) and reading, domain general processes, cognitive training, motivational, affective and social processes, and neurodevelopmental processes.

On the topics of STEM education, several factors critical for mathematical learning are discussed, from preverbal number representation, symbolic number knowledge, working memory and affective processes, an understanding that could promote further research and mathematics education. **Bugden, Dewind and Brannon** emphasize the importance of a preverbal number representation (the so-called approximate number system) for mathematical development. This representation is thought to be linked to the intraparietal sulcus of the human brain. The authors suggest that combining functional brain imaging and training studies would shed light on the role of this preverbal representation during the school years and that a better understanding of preverbal number representations may contribute to better mathematics education. **Merkley and Ansari** discuss controversies about the potential role of the preverbal number representations and instead, conclude that symbolic numerical skills are key in acquiring mathematical knowledge. They posit that multiple specific aspects of such symbolic knowledge should receive special attention in both research and educational practice. **Bae and Menon** address the role of domain general functions in mathematical development and propose that working memory processes, and especially visuo-spatial working memory, crucially contribute to mathematical development and may be key to understanding developmental dyscalculia (a selective deficit of mathematical understanding). **Mareschal** points to another specific aspect of domain general functions, inhibitory control, which is critical in learning new mathematical and scientific facts, and how this knowledge provides corroborating evidence for practices in the classroom. **Newcombe** examines science learning more broadly, and suggests that general spatial skills have wide relevance for learning processes and for scientific thinking in children. She advocates that improving spatial skills are malleable and that their training should be an important educational goal. **Chang and Beilock** go beyond the cognitive components of mathematical learning and urges the emotional side of this development to receive distinguished attention. They show that higher levels of mathematics anxiety (a negative emotional reaction to mathematics) are related to worse mathematical performance. They discuss several potential contributors to mathematics anxiety and raise the prospect of various interventions.

In the field of reading also, a wide range of topics are discussed from perceptual processes to domain general functions as well as socio-emotional factors that are critical for learning to read. There is a noticeable shift in the literature from taking one unified and domain-specific perspective on the development of reading and dyslexia (a selective deficit in word decoding, a.k.a. reading disorder or RD) to a more multifactorial approach. For example, **Vandermosten, Hoeft and Norton** examine pre-readers at-risk for developing dyslexia as a way to examine more causal mechanisms of dyslexia rather than impoverished reading experience, and show evidence for early and multiple deficits in phonological, orthographic, and low-level perceptual processing and anomalous communication between these processes. **Haft, Myers and Hoeft** link the concept of resilience to dyslexia by examining domain general cognitive and socio-emotional protective factors in those with neurobiological risk factors for developing RD who never develop, or develop only mild deficits in the core phenotypes relative to risk, and those who achieve good functional outcome relative to the severity of dyslexia. **Ozernov-Palchik, Yu, Wang and Gaab** integrate these as well as other findings and review the multiple deficit model, which has been proposed as a model that explains how outcome of multiple risks and protective factors interact at the genetic, neural, cognitive, and environmental levels in the phenotypic presentation of dyslexia. They build on this model, and further integrate a developmental perspective to the model to explain individual differences in reading development and the dyslexia phenotypes, which may ultimately have implications for educational practice.

Moving beyond STEM and reading, several papers dive into the importance of domain general functions such

as executive function. For example, **Blair** provides an overview of a growing body of evidence indicating the importance of executive function abilities and related contributors to school readiness and early school success, which are in turn highly relevant to early educational programs for children, especially those in impoverished environments. **Shanmugan and Satterthwaite** extend the significance of executive function and facilitation of these skills into childhood and young adulthood, and how atypical development helps us understand typical developmental processes. **Ofen, Yu and Cheng** review literature on the development of working memory, another aspect of domain general functions, how this process is constrained by brain maturation, and how our understanding of its interaction with prior knowledge, strategies used and metacognitive abilities may inform educational practices. **Klingberg** takes a step further and discusses training of working memory in the context of brain development. He poses the hypothesis that training and development involve similar neuronal processes. Such commonality would have implications for both the interpretation of research results and practical implementation of training programmes. **Steinbeis and Crone** direct attention to the importance of understanding the development of various cognitive control processes throughout childhood and adolescence in determining individual differences in future-oriented and social decision making. Adequate training of appropriate cognitive control components is likely to have lifelong influence on both individual well-being and academic achievement.

Turning to motivational, affective and social processes important for educational practice, several papers address these issues in addition to the aforementioned papers by Chang and Beilock on math anxiety and Haft, Myers and Hoeft on socio-emotional resilience in dyslexia. **Howard-Jones and Jay** focus on understanding game based learning with efficient and child-friendly game-like classroom interventions based on recent insights regarding midbrain responses to reward. They discuss the relationship of reward and attention processes, clarify important differences in terminology and questions between traditional neuroscience and education approaches, and emphasize the importance of increasing the evidence base of current educational approaches. **Van Hoorn, Fuligni, Crone and Galvin** point to how peer influence plays a key role in health-compromising risky behaviors as well as positive psychosocial outcomes such as enhancement of learning and prosocial behavior in adolescence. The review highlights the significance of motivational and social circuitries in these processes, and how taking advantage of knowledge gained, in particular about prosocial behavior, may be a promising avenue to promote school-based instructions/interventions. **McRae** describes various types of emotion regulation and suggests that cognitive reappraisal may be the most useful type in practical settings such as in schools. **Martin and Oschner** provide a framework for the development of emotion regulation as a critical skill that can facilitate learning and improve educational outcome. They point to differential neurocognitive developmental trajectories associated with regulation of positive and negative emotions, and the importance of the role of social contexts. Further, they discuss how we may capitalize on understanding of regulation strategies to enhance positive emotions and help educators better scaffold and manage their classrooms for enhanced learning and successful student outcomes. **Sheridan and McLaughlin** propose a novel model that links exposure to adverse experiences to education success, and specify particular dimensions of experience such as decreased social stimulation or presence of threat, rather than the type of exposure such as poverty, in impacting neurodevelopmental processes. They suggest that such models are useful in generating testable hypotheses and pathways for specific intervention strategies, and may be particularly useful in considering educational achievement for disadvantaged children.

Finally, several papers cover a broad topic of fundamental principles underlying neurodevelopmental processes that may guide educational instruction and interventions. **Haartsen, Jones and Johnson** discuss difference in the time-course of the emergence of functional specialization that is regionally specific, and how complex bidirectional relationships between structure and function including neural oscillation may contribute to the substantial resilience and adaptation shown by the developing brain, which may in turn be helpful in understanding optimal interventions. **Goswami** points to the importance of understanding how relatively low level neural information coding and transmission processes originating in sensory systems may inform our understanding of higher level cognitive processes relevant for education. She suggests that a better understanding of neural oscillatory mechanisms can inform our knowledge about language development and developmental dyslexia, and that we need to address causal developmental mechanisms going beyond structure/function correlations. **Dumontheil** reviews major changes in brain structure and function during adolescence and how these may relate to behavior characteristic of adolescence. She suggests that specific aspects of adolescent brain development such as Adolescent-specific sub-cortical reactivity to emotions and rewards contrasted with their developing self-control skills, have important implications for training programmes targeting adolescent populations. **Cooper and Mackey** take a unique approach by comparing the role of brain plasticity on visual and cognitive interventions. They take advantage of decades of basic research on the development and treatment of developmental visual disorders, which they argue may help to inform how cognitive training approaches can be tailored for students who experience environmental disadvantages.

Together, recent transdisciplinary research in the areas we cover in this special issue will provide us with a fine-grained and at the same time, a macroscopic view of cognitive, affective and social constructs important for educational practice. Our hope is that such research, discussions and new integrative models will further our understanding of learning and teaching, and ultimately lead to enhanced educational practices.

BIOGRAPHY: 70-100 words

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Fumiko Hoeft is Director of brainLENS and Associate Professor of Psychiatry, Weill Institute for Neurosciences, and Dyslexia Center at UCSF. Hoeft's research program focuses on brain mechanisms underlying skill acquisition such as reading and how it intersects with domain general cognitive processes and motivation. She received her research training at Harvard, Caltech and Stanford in neurophysiology, and systems and developmental cognitive neurosciences. Recent honors include the IDA's 2014 Norman Geschwind Memorial Lectureship, and Learning and the Brain's 2015 Transforming Education through Neuroscience Award. Hoeft has published over 115 articles in journals such as the PNAS and the Journal of Neuroscience. Her work has been covered in media such as The New York Times, NPR, CNN, the New Yorker and Scientific American.